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Evaluation of environmental aspects of brew waste-based carbon production and its disposal scenario

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ABSTRACT

The piece of work evaluates environmental impacts associated with the lab-scale production of 1 kg activated carbon (AC) as a functional unit from the obtainment of 2.14 kg feedstock. The environmental advantages over lignocellulose-based carbon, particularly in terms of acidification potential, non-renewable energy demand, and carbon footprint were considered. The quantification of environmental interactions over the stages of the life cycle of AC manufacturing chain, in terms of inputs of energy and natural resources and of outputs of emissions to the different environmental compartments, were studied. Drying (99.2%)and impregnation with an H_2SO_4(0.7%)attribute to major impact categories: carcinogens, respiration organics, respiration inorganics, climate change, radiation, the ozone layer, ecotoxicity, acidification, land use, minerals and fossil fuels. Disposal of AC might not affect the environment. On contrary, the predictions (human health(16.7%), ecosystem quality(0.928%), and resources(74.2%)) indicates that disposal of untreated brew waste might exhibit harmful effects to the environment hence improvements are necessary. In particular, the operations utilizing electricity, heat, natural gas and resources were the main factors causing emission to air, water and soil.

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1. Introduction

Active carbons (AC) are solid, adsorbent materials with pores, one of the wastewater additives attracting and holding organic chemicals from vapor and liquid streams inside it that has been produced from the organic fraction of mostly abundant solid waste or other lignocellulosic materials (Zhao et al., 2018). AC is generally furnished with developed holes or pores to remove or purify the dilute concentrations of contamination from the water or wastewater. Production of AC relies on the conversion of agricultural waste to carbonaceous material (Vishnuganth et al., 2016) that will reduce the demand for new resources; cut down the cost and effort to transport and production, otherwise loss to landfill. Domestic or commercial waste including kitchen waste, brewing waste, plastics, paper, packaged products, wood, glass and metal found to be ground after each commercial usage (Rangabhashiyam et al., 2016). That is possible to produce non-hazardous carbon products. In regard, brew waste (BW) avails carbon and naturally homogenous in various composition (Ye et al., 2017). Due to abundant supply, high density and purity, BW can be chosen as carbon precursor; with the appropriate method of activation to produce the widely used non-hazardous carbon-bearing product “activated carbon” (AC) (Shujing et al., 2017).

In spite of extracting carbon precursor from waste feedstock (Haipeng et al., 2017), investigation on utilizing them displays complication associated with operation or production. It is believed that discerning is helpful in waste collection protocol and the unit of resources and processing them in order to inflate the quality of by-product or end product (Rathore and Mondal, 2018). In general, waste is transported to laboratory from the collection channels, is able to cause emission to various environmental compartments. Then segregation of foreign materials occurs followed by shredding them to minimize or obtaining a uniform particle size. Further pre-treatment begins with the subsequent steps of surface activation and modification. Carbonization of raw material begins with the exclusion of air followed by gasification and oxidization of carbon intermediate that will help in enrichment of carbon with pores (Alhasimi and Aktas, 2017).

Chemical activation of carbon is in practice, specifically, acidic activation had experimented at lab scale during which amorphous

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carbon whose crystallites were burnt off (Arena et al., 2016). With effect, the pores of carbon were developed from small to large as a basic grade of quality adsorbent. The resultant is so called "carbon intermediate", undergoing surface modification. In which, structure of material and quantitatively amount of carbon is uplifted. The number of inorganic components and their composition is superior characteristic (Ren et al., 2017) for an adsorbent having greater efficiency, high degree of porosity, specific surface chemistry and an extended surface area. Ultrasonication is performed to oxidize carbon material at 24 kHz working frequency with local temperature around 5000 K at local pressure 500 atm, with heating and cooling rates greater than 109 K/s. Collision between the particles (Sim and Prabhu, 2018) while passing ultrasonic waves through a liquid medium will form ultrasonic cavitation and chemical effects. At this extreme condition, water molecules are broken down to hydrogen and hydroxyl radicals (Qi et al., 2018) as an evident for chemical reaction. Thus, contaminants become ease to adhere on the surface of carbon or immobilize them in their small pores. Such carbons are efficient in removing certain organics, chlorine, fluorine and odour. In accordance with microbial contaminants, metals, nitrates and other inorganic contaminants, the lesser particle size of carbon is preferred. Mean size of particle (10–50 μm), amount of carbon (70–82%), ash content (2–5%), pore volume (0.95–1.2 ml/g), activating agents, hardness (80–95 HV) and surface area of activated carbon (2896–3287 m^2/g) are key variables to be considered in real time wastewater application (Hischier et al., 2017).

Reliable supply of AC must gain public attention through economic affordability and eco-friendly environmental profile. Environmental impact assessment of AC originally begins from the selection of feedstock (low inorganics), production processes, disposal and life cycle analysis. The aid of chemicals during production may release greenhouse gasses (Wang et al., 2018) and emission to air, water and soil. Such interactions can be encountered in life cycle assessment (LCA) based on different environmental compartment (air, water and soil) through quantifying input materials and energy or balancing input/output namely, release of chemicals, water and energy (Saffarain, 2009).

LCA was adopted to evaluate the production processes, disposal of AC and its reuse. Impacts of production process or treatment method must be eco-friendly and ease of access based on the waste hierarchy (Hong et al., 2018). In which, comparing a multiple scenario over a common problem provides possible decision in order to avail facility or type of waste for the production of AC. The previous limitations found in traditional tool is boundary setting, the open-loop allocation, the multi-loop allocation and problems associated with time as a system boundary (Hjaila et al., 2013). This makes LCA boundary to become wide and difficult to handle. Further, eco or environmental indicators were inappropriate, resulting in greenhouse gas emission and ozone depletion. Modern LCA tools overcome all of these, offers equivalent functions to each process and products. Indeed, manufacturers are unaware of eco-indicators, that may lead to negative exploitation of market demands (Friedrich and Buckley, 2002). Thus, LCA system based on local environmental policies with global impacts can be used.

The shortcomings of LCA standard is to avoid uncertainties which is associated in data collection, system boundary setting, model designing, product estimation, etc. The reliability of LCA result is purely based on the quality of inventory data (Rosenbaum et al., 2015). The lack of input data or accuracy can cause uncertainty. The accuracy of final data can be in strict correlation with physical process flow of other reports to avoid incorrect decision. Lack of knowledge in comprehensive LCA database may affect life cycle inventory (LCI) analysis. Because primary data or field data are ambiguous, incapable to analyses the data quality. As the production route is clear, comparison of LCA results at cross levels (Smebye et al., 2017) can be easier. Besides, LCA is predictive to analyses the whole cycle of production and disposal and their relevant environmental impacts. However, LCA database does not analyze the origin of contaminants and their release in environment that crossed the boundary. Impact evaluation is based on regional characteristics that considers both temporal and spatial variation in which consumption of resources and waste generation is prioritized. Their entry level into environment, sensitivity, availability of decision support variables may integrate the process efficiency, economic and social analysis (Arena et al., 2016).

The present system demonstrates the production of brew-waste based AC at lab scale, experimented in India obeyed the ISO 14040 series on LCA. By developing mass and energy balances at every step, authors tried to eliminate environmental burdens through life cycle analysis. Although, major three environmental compartments (air, water and soil) and greenhouse emission for the whole production cycle was evaluated. The average emission rate was established by introducing a function of waste flow in all the phases of production. The regional characteristics of sustainable assessment of AC production was estimated. This is how energy management and conservation of natural resources and environment is focused in the AC production.

2. Materials and methods

2.1. Compartments of LCA

The LCA compartment divide the process into four phases to show a comparatively better environment performance.

2.1.1. Origin of data

The data input/output retrieved was based on the lab-scale production of AC, experimented at the Department of Chemical Engineering, SSN College of Engineering, Chennai, India. Transport of BW from collection channels to the laboratory was 2 km apart. The present system including processing of waste material to final product including disposal was prime concerned. The supply of feedstock, energy, resources and their reuse were considered in the whole production cycle.

2.1.2. The scope of the study

Producing 1 kg of AC as a functional unit from the utilization of 2.14 kgraw material extends the scope of the current study and whose environmental impacts were examined.

2.1.3. System boundary

System boundary is a set of criteria specifically designed for the production processes of AC which include ten steps. 1) transporting the exhausted BW to the laboratory; 2) drying the raw material; 3) crushing the dried material; 4) impregnating with H_2SO_4; 5) washing with water and filtering; 6) drying and cooling; 7) ultrasonication; 8) filtering; 9) drying and 10) crushing the final material. The quantification of input/output mass, energy, resources were done in each process steps. The system boundary was partially set for the waste disposal. The collection of waste and storage were excluded from the life cycle scenario since it is obvious.

2.1.4. Life cycle assessment

Transportation of waste from the collection channel to where processing of waste occurred is possible for direct emission to air, water and soil followed by disposal of waste on the life cycle. These were analyzed since the production involves drying, heat exchange by natural gas and activation through chemical impregnation and

ultrasonication. Each of these treatment methods was adopted to pulverize AC after primary and secondary crushing. Among them, chemical treatment contributes major effect by adding hydrogen, sulfur and oxygen groups. In such way, pores were developed around the core of AC, used in later scenarios for adsorbing water pollutants. In addition, disinfectants were added to the raw material in the case to dispose of directly without further treatment. After experimenting with a removal of a specific pollutant, the regeneration efficiency and direct disposal of AC in a hazardous waste incineration site were analyzed.

2.2. Application of LCA methodology

Simapro 8.5.0. was adopted to implement LCA methodology. LCA involves in adapting alternate sources to modify or optimize the process steps for sorting out the environmental weakness. The functional unit of LCA boundary is defined as 'p' (in percentage). Life cycle inventory (LCI) analysis consists of processes, product stages, system description, waste types and parameters to quantify the waste adopted for the study. Raw material, energy input, and output flows are considered based on the functional unit within the LCA boundary. Life cycle impact assessment (LCIA) defines the suitable methods and calculation setups in correspondence to developed environmental policies (Yu and Tao, 2009). The aim of impact assessment is to evaluate the significance and intensity of the current system based on eco-indicators. It also attributes to specific characteristics of impact categories. Interpretation will help in making decisions, recommendations, and conclusions based on the previous report. It also covers regional environmental policies.

2.3. Characterization factors

Afore claimed applications were inspected using the software Simapro 8.5.0 based on the eco invent database v2.2 (Swiss Centre for Life Cycle Inventories, SCLCI, 2018) to obtain the background data. The impact categories surveyed in the present system is carcinogens, respiration organics, respiration inorganics, climate change, the ozone layer, ecotoxicity, acidification or eutrophication, land use and minerals. These midpoint categories are efficient to minimize regional characteristics of a specific product. Based on information provided in LCA methodology, the economic and social impact was assessed using internal/external factors (market demand, ecosystem quality, resources, and human health protection). Based on the supplementary note, manufacturers must know the current market scenario for the AC production with effect to low charge on environmental pollutants and eco-remediation demands that include willingness-to-pay cost (Guinee, 2012). It varies from country to country based on actual human health rate, energy, cost investments and social health expenditure followed by government expenditure on public health.

2.4. Physical waste flow analysis

The background data of 1 kg AC production include energy utilization in the form of electricity and heat, chemicals like H_2SO_4 with effect to the emission of heavy metals and natural gases and disposal were inspected with the help of regionalized effect adapted from European environmental protection agency. To complete the life cycle inventories, missing secondary data were obtained from the literature and the Eco invent database.

Due to the lack of output data or accuracy of waste scenarios in the ecoinvent database, the secondary output flows were assumed from different waste scenarios. Thermodynamic equations were adapted to calculate the energy uses. The ideal gas law was used to measure the nitrogen gas flux weight. Water output flows were collected, weighed in the discharged site. The water contaminated with H_2SO_4 after washing was assumed to be untreated, discharged with organic and inorganic contaminants which can become carcinogens in the disposal site. Such waste stream was not available in the ecoinvent database, however, considered to be less critical (Hsien et al., 2012). With reference to previous studies, LCA is used to enhance the material functionalities in order to reduce the environmental burdens, simultaneously, enhancing their life-span in its daily exposure to the environment.

The major contribution of each production step and its waste scenario was used to explore damage category. In which, impacts on human health, ecosystem quality and resources were detected. Such broad and comprehensive characteristics of ecotoxicity potential, the related amount of released chemical compounds and disposal via transport were analyzed.

3. Results and discussion

3.1. Evaluation of environmental impacts of AC

3.1.1. Results of system boundary

Based on the experimental data, the inventory results of 2.14 kg of feedstock processed for the production of 1 kg AC has adapted in correspondence to the input and output materials, energy, and emissions. Fig. 1 illustrates that 2.14 kg of exhausted BW utilizes heat energy (128.62 kWh) during drying and slowly releasing 0.23 kg H_2O as the function of cooling. Then crushing is the mechanical operation utilized 184.5 kWh energy to produce 0.354 mm particle size of carbon precursor. The resultant was weighed and reported as 1.91 kg. Manual impregnation of 1.76 kg H_2SO_4 as activating agent was used in an undisturbed manner for 24 h at 20 °C. Because chemical activation is advantageous over physical activation in reducing operational cost while enriching the percentage of carbon yield. Moreover, this acidic bath is cheaper and cost effective to bring a quality adsorbent with maximum active sites. In addition, sulphuric acid is an eco-friendly catalyst, obviously having moderate acute toxicity (short-term) on aquatic life. The exposure of H_2SO_4 in the air is released to atmosphere and exposure to water and soil will definitely impact the aquatic and human life. In concern, the contented 3.67 kg of acid mixture was removed using 8.26 kg of water. 4.42 kg of acid treated out of 7.80 kg carbon intermediate was obtained.

This intermediate was directly subjected to ultrasonication through utilizing 40 kg of H_2O. After filtration, 3.30 kg AC was retained followed by drying at 80 °C for 12 h. 3.80 kg of AC was crushed to bring unit particle size between 10 and 50 μm. Around 1 kg of final material as a functional unit of a product was obtained, named AC. The loss of raw material during the production steps is not critical but manageable. The loss of water source or discharge of water is high at lab scale, yet, the industrial scale may need lesser number of sources due to the sophisticated infrastructure and facilities. The differences in energy consumption, resources utilization, and mechanical operation conditions, the price of the final product may vary. The lab scale AC production has utilized less amount of energy as compared to previous reports, reported elsewhere.

3.1.2. Quantification of input/output variables in production scale

Table 1 demonstrates the overall data of material input in utilizing resources, chemicals, and energy and which was further balanced with data of material as the amount of water released in drying, washing and sonicating.

The contribution of each step namely, drying, chemical impregnation, electricity, ultrasonication, production of 1 kg AC, disposal of brew waste, transport and waste recycling is

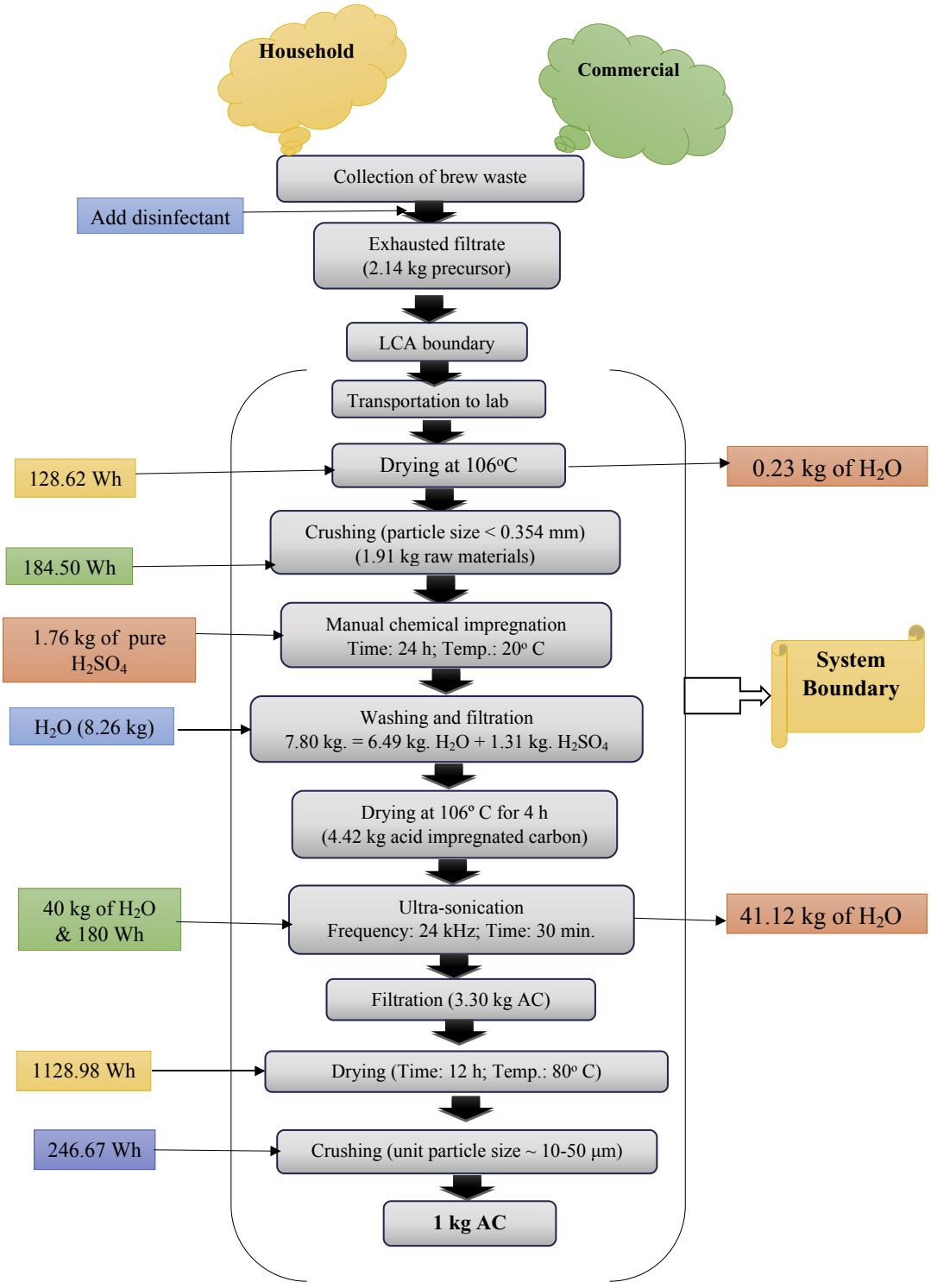

Fig. 1. Physical flow of the AC production.

incorporated in Table 2. Among them drying plays a crucial role in both of carbon precursor (99.2%) and AC (98.6%). Disposal of these waste or processed material in environment showed in negative values, representing positive impacts to the environment. By any chance, if disposal values are positive, that is a sign of negative impacts on the environment (Levis et al., 2017). Notably, disposal of BW as carbon material can be disposed of whereas no value was found as disposal of AC, indicating a sign of regeneration or reuse. However, recycling of BW is negative indicating for no efficiency in the performance of exhausted waste. Recycling of AC was not even found to be feasible since the biomass is completely utilized. Disposing untreated BW can harm the environment as the results are positive, it may negatively impact the environment.

3.1.3. *Overall impact categories of AC produced*

The overall impact category of AC produced and its disposal is

Table 1
Quantification of material input-output in the AC production.

Name	Experimental lab amount (g)	Adapted amount (kg)
Material Input		
Brew waste	80	2.14
H_2SO_4 (Pure)	65.79	1.76
H_2O utilized for primary washing (H_2SO_4)	4.05	8.26
H_2O utilized for ultrasonication	800	40
Material Output		
Wastewater derived from drying the raw material	0.10	0.23
Wastewater derived from impregnation	2.98	6.49
Wastewater derived from ultrasonication	600	36.12
Wastewater derived from drying the filtered AC	80.12	2.40
Activated carbon	40.25	1.0

reported in Table 3. The respective categories namely, carcinogens, respiration organics and respiration inorganics, climate change, radiation and ozone layer with the unit of "disability-adjusted life year" (DALY) followed by ecotoxicity with the unit of "potential of affected fraction of species in relation to a toxic concentration" (PAF*m^2yr) followed by acidification or eutrophication, and land use with the unit of "potential of disappeared fraction of plant species" (PDF*m^2yr), and minerals and fossil fuels with the unit of "MJ surplus" as MJ energy per year per capita was investigated. The global environmental burden of produced activated carbon in terms of DALY units was found to be within the permissible limits that a weight factor reflects the severity of AC.

Fig. 2 presents the various categories on disposal scenario. The negative values of which indicate a positive impact on the environment. In general, ecotoxicity and acidification tend to define ecosystem quality in relation to a toxic substance. Having minerals and fossil fuels in the range of less than 2.5 indicates that extraction of BW in future will require additional MJ of energy to compensate resource extraction (Guinee et al., 1993). It is further explained by the small variations of minerals and fossil fuels found on the environment as damages. The eco indicator 99 provides different weighting perspectives. According to this model, the hierarchy in damage scenario by minerals and fossil fuels are 0.115 and 175 respectively. Exposure of these on long or short-term to AC produced average weighting factor as damage perspective.

3.1.4. Process-specific impact categories

The process specific impact categories are shown in Fig. 3 that demonstrates the main contribution by ultrasonication (95%) as being the last production step. Rest of it, carbon precursor shares 5–10% of all category and 2–30% by chemical treatment and transport is less than 0.5%. They are subjective to public/environment safe-guard namely, ecosystem quality, human health and resources (aesthetic values). Table 4presents the human health indicator which is mainly influenced by drying (14%), chemical impregnation (2.64%), ultrasonication (0.067%) and transport (0.000216). The influence of natural gas and heat exchange (Thornley, 2008) plays a crucial role in drying; followed by the aid of chemicals in surface activation of carbon; ultrasonic waves presenting narrow dispersion of carbon molecules and finally transport whereas exposure level is low as the material is tightly packed for market distribution.

Ecosystem quality indication from Fig. 4 in all the steps (0.776, 0.146, 0.0055 and $2.33*10^{-5}$% respectively) is significantly found less, indicating no harmful effect can be made to the environment by produced AC. It is noted that elementary factor of water is not rated as resources. However, utilization of resources (materials & energy) for each step brings societal values found around 62.4% in drying, 11.8% in H_2SO_4 impregnation, 0.098% in sonication and 0.000165% in transport. In the viewpoint of authors, the production scale or process do not hinder environmental safety.

3.1.5. Disposal scenario of waste

In each production step, waste was expected either in the

Table 2
Environmental aspects of each step in the production.

No	Process	Total (%)	Activated Carbon (%)	Disposal of Activated carbon (%)
	Total of all process	100	100	−100
1	Drying (Heat, natural gas, industrial oven)	99.2	98.6	−98.5
2	Impregnation of chemicals	0.79	0.768	−0.766
3	Electricity	0.362	0.353	−0.353
4	Ultrasonication	0.285	0.283	−0.283
5	Production of AC	0.041	0.040	−0.04
6	Disposal of brew waste	0.006	–	0.0004
7	Transport	0.0008	0.0007	−0.0007
8	Recycling waste	−0.654	–	−0.0418

*Negative sign in the disposal of AC indicates no or shows positive impacts to the environment.

Table 3
Overall impact category of waste disposal scenario.

No	Impact category	Unit	Total	Activated carbon	Disposal of activated carbon
1	Carcinogens	DALY	$2.74*10^{-3}$	$8.73*10^{-6}$	$-8.46*10^{-6}$
2	Respiration organics	DALY	$5.39*10^{-8}$	$8.86*10^{-7}$	$-8.32*10^{-7}$
3	Respiration inorganics	DALY	$7.26*10^{-6}$	0.000128	−0.00012
4	Climate change	DALY	$1.58*10^{-5}$	0.000261	−0.000246
5	Radiation	DALY	$2.63*10^{-8}$	$4.36*10^{-7}$	$-4.1*10^{-7}$
6	Ozone layer	DALY	$9.69*10^{-9}$	$1.6*10^{-7}$	$-1.51*10^{-7}$
7	Ecotoxicity	PAF*m2yr	0.813	14.4	−13.6
8	Acidification/Eutrophication	PDF*m2yr	0.309	5.16	−4.85
9	Land use	PDF*m2yr	0.47	7.78	−7.32
10	Minerals	MJ surplus	0.115	2.13	−2.02
11	Fossil fuels	MJ surplus	175	$2.9*10^3$	$-2.72*10^{-3}$

* Negative sign in the disposal of AC indicates no or shows positive impacts to the environment.

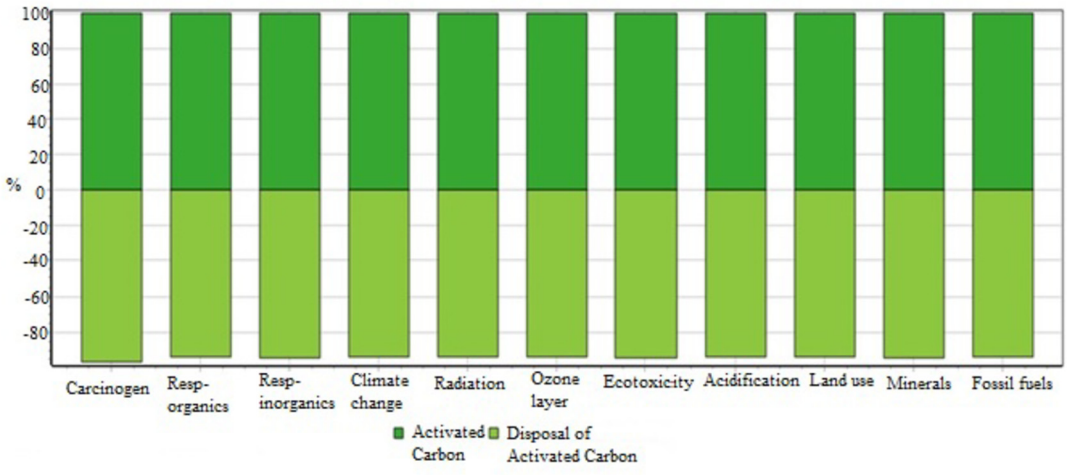

Fig. 2. Overall impact category of waste disposal scenario.

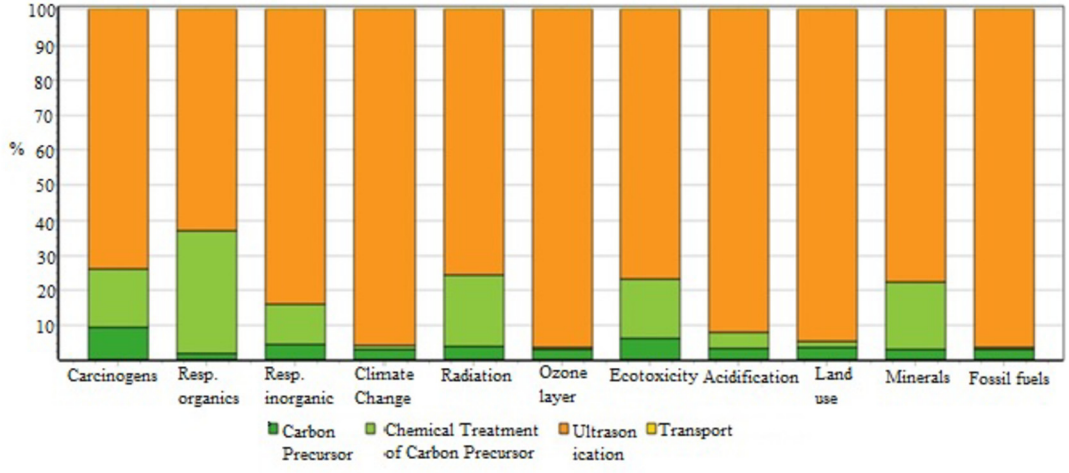

Fig. 3. Overall impact category of each production step.

Table 4
Indicators of impact assessment.

No	Damage Category	Total (%)	Drying (%)	Chemical Impregnation (%)	Ultrasonication (%)	Transport (%)
	Total	91.9	77.2	14.5	0.171	0.000405
1	Human Health	16.7	14	2.64	0.067	0.000216
2	Ecosystem quality	0.928	0.776	0.146	0.00559	$2.33*10^{-5}$
3	Resources	74.2	62.4	11.8	0.098	0.000165

form of energy or resources or biomass which was studied using LCA inventory. In accordance with the material input, the raw material reported in Table 5, it found to be eliminated from the process around 0.511 kg out of 2.14 kg after chemical impregnation; 0.126 kg after ultrasonication and unreported 0.200 kg during crushing. This can be neglected since the loss of feedstock is less. H_2SO_4 contaminated waste (biomass) was removed around 0.959 kg and 0.236 kg after dual surface modification as washing took place largely. In context, the waste to be directly landfilled was estimated around 1.37 kg and 0.338 kg after each production steps. The physical waste flow shows the maximum obtention of raw material in order to produce 1 kg AC.

3.2. Assessment of production scale to various environmental compartments

3.2.1. Emission to air, water, and soil

The current production system is attributed to two main factors: the amount of energy and materials used at different input levels, assumption and production scales. The overall process flow leads to the emission of air, water, and soil as primary environmental compartments were considered. In reality, no societal and economic issues were found in this regard. Chemical activation of carbon precursor while drying and cooling is possible to expose in the atmosphere causing methane emission as natural gas released from drying of carbon material (Dahmen et al., 2018). Using H_2SO_4

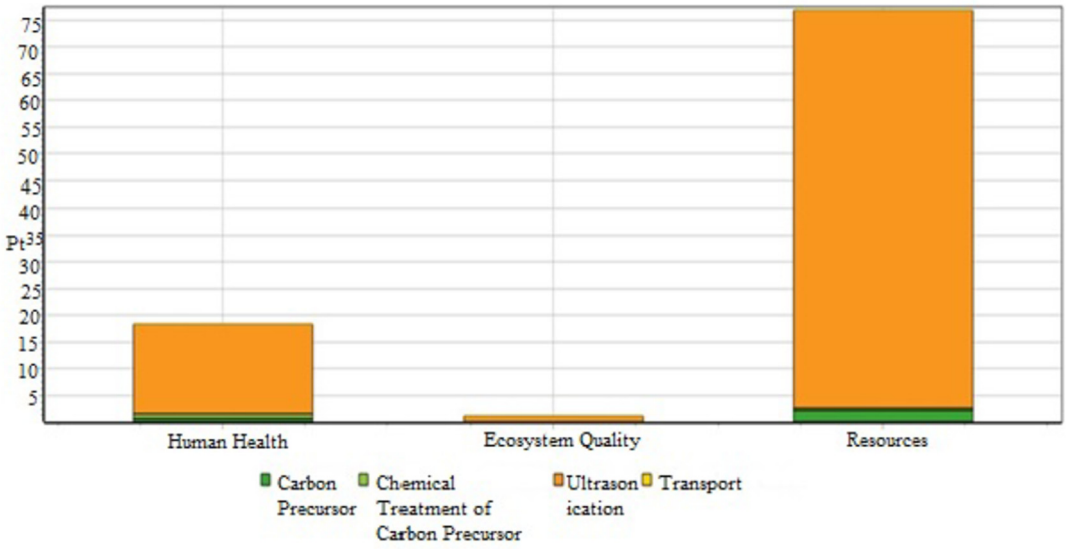

Fig. 4. Impact assessment of each production step.

Table 5
Life cycle inventory of physical waste flow.

No	Substance	Compartment	Total (kg)	Chemical treatment (kg)	Ultrasonication (kg)
1	Raw material	Waste	0.637	0.511	0.126
2	Chemical waste (H_2SO_4 contaminated)	Waste	1.2	0.959	0.236
3	Bioactive waste in landfill	Waste	1.71	1.37	0.338

is the main cause for identifying acidification potential and toxicity impacts in the produced AC. The relative contribution of AC to various pollutants like carbon dioxide as the evidence of the greenhouse effect was noted. This is obvious as the production involves heating up raw material. The supply of energy in the form of heat also contributes emissions to all three compartments.

Table 6 presents the possible important substances causing airborne emission with significant quantities. Unit of each substance is reported for three distinct categories of material namely, raw material, acid treated carbon intermediate and ultrasonicated AC followed by transport of end-product. Among the list of substances, heavy metals and organic solvents were identified as auxiliary materials (Edwards et al., 2017) that would reflect in the extraction of resources, production, and disposal. Carbon dioxide (biogenic) was found to be in mg and few of others were in μg and g. However, the estimated amount does not exceed the permissible limit.

With effect to sensitivity analysis, certain substances were found causing waterborne emission, reported in Table 7. Notably, arsenic and hydrocarbons were identified in mg, a severe damage to water sources. It can be eliminated by modifying the production channel or alternate use of chemicals. Indeed, the present system

Table 6
Airborne emission of each production step.

No	Substance	Unit	Total	Raw material	Chemically treated AC	Ultra-sonicated AC	Transport
1	Acetaldehyde	mg	28	1.28	3.16	23.5	0.0001
2	Arsenic	mg	5.61	0.384	1.25	3.98	0.0003
3	Benzene	g	8.29	0.225	0.854	7.21	0.0002
4	Boron	mg	239	14.5	49.1	175	0.0031
5	Butane	g	17.6	0.489	0.118	17	0.0000
6	Cadmium	mg	1.99	0.0979	0.459	1.43	0.0001
7	Carbon-dioxide (biogenic)	mg	622	120	66.4	436	0.0073
8	Carbon disulphide	mg	130	4.91	25.1	100	0.0153
9	Ethane	g	92.3	2.51	0.701	89	0.0000
10	Helium	mg	17.4	0.724	0.837	15.9	0.0017
11	Hydrocarbons, aliphatic, alkanes	mg	757	757	0.389	0.00727	$3.32*10^{-7}$
12	Iodine	mg	9.96	1.87	2.15	5.94	0.0001
13	Lead	mg	44.4	1.65	15.5	27.2	0.0017
14	Manganese	mg	8.19	0.806	1.91	5.47	0.0002
15	Methanol	mg	47.6	8.48	8.8	30.3	0.0020
16	Nitrogen oxides	g	795	25.2	23	747	0.0125
17	Potassium	mg	86.5	15.3	14.4	56.8	0.0009
18	Selenium	mg	2.22	0.282	0.492	1.45	$7.21*10^{-5}$
19	Sodium	mg	21	2.35	4.67	14	0.0008
20	Titanium	mg	1.82	0.641	0.459	0.718	$5.97*10^{-5}$

Table 7
Waterborne emission of each production step.

No	Substance	Unit	Total	Raw material	Chemically Treated AC	Ultra-sonicated AC	Transport
1	Acetaldehyde	µg	789	665	123	–	–
2	Arsenic	mg	72.6	8.69	13.2	50.6	0.0031
3	Benzene	g	48.3	16.5	3.73	28	0.0030
4	Boron	mg	590	64.4	127	398	0.0072
5	Butane	g	17.6	0.489	0.118	17	0.0000
6	Cadmium	mg	43.8	2.54	4.23	37.1	0.0020
7	Carbonate	mg	45.2	3.43	6.23	35.6	0.0019
8	Chlorinated solvents	µg	507	70.6	124	312	0.0225
9	Ethane	µg	116	6.51	12.8	96.3	0.00191
10	Heat, Waste	MJ	11.3	0.279	1.65	9.4	0.00066
11	Hydrocarbon, aliphatic, alkanes	mg	30.4	1.61	2.83	26	0.0051
12	Iodine	mBq	156	105	26.8	23.9	0.0009
13	Lead	mg	217	11.5	28.8	176	0.0136
14	Manganese	g	2.43	0.867	1.31	0.25	$6.01*10^{-6}$
15	Methanol	mg	387	10.8	1.96	374	$7.58*10^{-5}$
16	Nitrate	g	3.3	1.21	1.65	0.435	$3.32*10^{-5}$
17	Potassium	g	24.3	7.51	11.4	5.36	0.0002
18	Selenium	mg	14.1	4.23	6.27	3.56	$8.57*10^{-5}$
19	Sodium	g	122	17	26.4	78.2	0.0186
20	Titanium	g	1.2	0.32	0.196	0.681	$4.85*10^{-5}$

Table 8
Emission to the soil by the production steps.

No	Substance	Unit	Total	Raw material	Chemically Treated AC	Ultra-sonicated AC	Transport
1	Aclonifen	µg	2.72	0.0772	0.134	2.5	0.0016
2	Arsenic	mg	1.07	0.0313	0.0106	1.02	$7.32*10^{-6}$
3	Bentazone	µg	1.71	0.267	0.17	1.27	0.0008
4	Boron	mg	34.6	0.959	2.21	31.4	0.0002
5	Calcium	g	10.8	0.335	0.116	10.3	$7.46*10^{-5}$
6	Cadmium	mg	17.1	2.57	2.73	11.7	0.0158
7	Carbon	g	7.99	0.232	0.0755	7.69	$5.59*10^{-6}$
8	Chloride	g	10.3	0.29	0.0947	9.88	0.0094
9	Chromium	mg	13.5	0.408	0.14	12.9	0.0002
10	Heat, Waste	MJ	8.98	0.164	2.29	6.53	$7.11*10^{-5}$
11	Iron	g	5.87	0.178	0.161	5.53	$4.64*10^{-5}$
12	Linuron	µg	25.8	3.52	2.86	19.4	0.0126
13	Lead	µg	134	15.9	49.9	67.9	0.0792
14	Manganese	mg	116	5.33	2.64	108	0.0008
15	Metolachlor	µg	164	8.26	15.3	140	0.0912
16	Nickel	µg	113	10.6	14.4	88.2	0.126
17	Oils, biogenic	mg	12.7	2.54	3.2	7.01	0.0001
18	Strontium	mg	26.5	0.755	0.23	25.5	0.0001
19	Zinc	mg	50.5	1.67	2.66	46.1	0.0129
20	Titanium	µg	799	165	200	434	0.0072

did not adopt rare or expensive chemical except H_2SO_4 that can be recovered for secondary usage. Availing ultrasonication ensures "no secondary pollution" (Jakovljević et al., 2018). Thus, immediate environmental action can take place based on the predicted hazardous substances.

Table 8 presents emission to the soil by produced AC that material runoff from the production route, assumed to be landfill. In this perspective, AC may hinder aquatic & human life as the recycling of raw material cause negative impact on the environment. Therefore, recycling possibilities can be eliminated from the viewpoint of researchers. Disposal of exhausted feedstock is strictly prohibited in order to prevent soil quality and support habitation. In context, these suggestions can be considered by the practitioner for the production of AC from solid waste in order to design operation, prevent environmental emissions and develop economic profit.

4. Conclusion

Brew waste-based AC was produced in a simple way at lab scale with a mean particle size between 10 to 50 µm. The operating conditions, internal pore development and unique sorption properties of AC was considered throughout a production cycle. Impurities after each production processes were eliminated in batch mode. The disposal of produced AC was found be positively impact the environment whereas exhausted feedstock without treatment causes negative impact. Human health where different disability caused by diseases were weighted based on district impact categories. The results conclude that lower concentration of energy is required in future for resource extraction. The damage perspective of developed AC is the hierarchy which balances short and long-term exposure. In contrast, emission to air, water and soil by predicted substances were not exceeded the environmental permissible limit.

References

Alhasimi, H.A., Aktas, A.B., 2017. Life cycle environmental and economic performance of biochar compared with activated carbon – a meta-analysis. Resour. Conserv. Recycl. 118, 13–26.
Arena, N., Lee, J., Clift, R., 2016. Life cycle assessment of activated carbon production from coconut shells. J. Clean. Prod. 125, 68–77.
Dahmen, J., Kim, J., Ouellet-Plamondon, C., 2018. Life cycle assessment of emergent

masonry blocks. J. Clean. Prod. 171, 1622–1637.
Edwards, J., Othman, M., Crossin, E., Burn, S., 2017. Life cycle assessment to compare the environmental impact of seven contemporary food waste management systems. Bioresour. Technol. 248, 156–173.
Friedrich, E., Buckley, C.A., 2002. The Use of Life Cycle Assessment in the Selection of Water Treatment Processes. A Report by Water Research Commission. Durban.
Guinee, J.B., 2012. Life Cycle Assessment: Past, Present and Future. International Symposium on Life Cycle Assessment and Construction, France.
Guinee, J.B., Udo, H.A., Huppes, G., 1993. Quantitative life cycle assessment of products: 1:Goal definition and inventory. J. Clean. Prod. 1 (1), 3–13.
Haipeng, W., Cui, L., Guangming, Z., Jie, L., Jin, C., Jijun, X., Juan, D., Xiaodong, Li, Junfeng, L., Ming, C., Lunhui, L., Liang, H., Jia, W., 2017. The interactions of composting and biochar and their implications for soil amendment and pollution remediation: a review. Crit. Rev. Biotechnol. 37 (6), 754–764.
Hischier, R., Salieri, B., Pini, M., 2017. Most important factors of variability and uncertainty in an LCA study of nanomaterials – findings from a case study with nano titanium dioxide. Nanoimpact 7, 17–26.
Hjaila, K., Baccar, R., Sarra, M., Gasol, C.M., Blanquez, P., 2013. Environmental impact associated with activated carbon preparation from olive-waste cake via life cycle assessment. J. Environ. Manag. 130, 242–247.
Hong, J., Zhan, S., Yu, Z., Hong, G., Qi, C., 2018. Life-cycle environmental and economic assessment of medical waste treatment. J. Clean. Prod. 174, 65–73.
Hsien, Y., Lin, S., Lewis, C., 2012. Life cycle assessment of fuel selection for power generation in Taiwan. J. Air Waste Manag. Assoc. 57, 1387–1395.
Jakovljević, I., Mijailovic, R., Mirosavljevic, P., 2018. Carbon dioxide emission during the life cycle of turbofan aircraft. Energy 148, 866–875.
Levis, J., Weisbrod, A., Hoof, G., Barlaz, M., 2017. A review of the airborne and waterborne emissions from uncontrolled solid waste disposal sites. Crit. Rev. Environ. Sci. Technol. 47 (12), 1003–1041.
Qi, Y., Chen, X., Wang, W., 2018. Improved life cycle assessment of recycling organic wastes for practice. J. Clean. Prod. 195, 1558–1571.
Rangabhashiyam, S., Suganya, E., Selvaraju, N., 2016. Packed bed column investigation on hexavalent chromium adsorption using activated carbon prepared from Swietenia Mahogani fruit shells. Desalin. Water Treat. 57 (28), 13048–13055.
Rathore, V.K., Mondal, P., 2018. Life cycle assessment of defluoridation of water using laterite soil-based adsorbents. J. Clean. Prod. 180, 716–727.
Ren, C., Wang, W., Mao, Y., Yuan, X., Song, Z., Sun, J., Zhao, X., 2017. Comparative life cycle assessment of sulfoaluminate clinker production derived from industrial solid wastes and conventional raw materials. J. Clean. Prod. 167, 1314–1324.
Rosenbaum, K.R., Meijer, A., Demou, E., Hellweg, S., Jolliet, O., Lam, N., Margni, M., McKone, T., 2015. Indoor air pollutant exposure for life cycle assessment: regional health impact factors for households. Environ. Sci. Technol. 49, 12823–12831.
Saffarain, S., 2009. A LCA Study of Activated Carbon Adsorption and Incineration in Air Pollution Control. Thesis. University of Borås, School of Engineering.
Shujing, Y., Guangming, Zeng, Haipeng, Wu, Chang, Z., Jie, L., Juan, D., Zhifeng, L., Weiping, X., Jia, W., Piao, X., Min, C., 2017. Co-occurrence and interactions of pollutants, and their impacts on soil remediation—a review. Crit. Rev. Environ. Sci. Technol. 47, 1528–1553.
Sim, J., Prabhu, V., 2018. The life cycle assessment of energy and carbon emissions on wool and nylon carpets in the United States. J. Clean. Prod. 170, 1231–1243.
Smebye, A.B., Sparrevik, M., Schmidt, H., Cornelissen, G., 2017. Life cycle assessment of biochar production systems in tropical rural areas: comparing flame curtain kilns to other production methods. Biomass Bioenergy 101, 35–43.
Thornley, P., 2008. Airborne emissions from biomass-based power generation systems. Environ. Res. Lett. 3 (1), 014004.
Vishnuganth, M.A., Remya, N., Kumar, M., Selvaraju, N., 2016. Photocatalytic degradation of carbofuran by TiO_2-coated activated carbon: model for kinetic, electrical energy per order and economic analysis. J. Environ. Manag. 181, 201–207.
Wang, J., Wu, H., Duan, H., Zillante, G., Zuo, J., Yuan, H., 2018. Combining life cycle assessment and building information modelling to account for carbon emission of building demolition waste: a case study. J. Clean. Prod. 172, 3154–3166.
Ye, S., Zeng, G., Wu, H., Zhang, C., Dai, J., Liang, J., Yu, J., Ren, X., Yi, H., Cheng, M., Zhang, C., 2017. Biological technologies for the remediation of co-contaminated soil. Crit. Rev. Biotechnol. 37 (8), 1062–1076.
Yu, S., Tao, J., 2009. Simulation based life cycle assessment of airborne emissions of biomass-based ethanol products from different feedstock plantings areas in China. J. Clean. Prod. 17, 501–506.
Zhao, W., Yu, H., Liang, S., Zhang, W., Yang, Z., 2018. Resource impacts of municipal solid waste treatment systems in Chinese cities based on hybrid life cycle assessment. Resour. Conserv. Recycl. 130, 215–225.